Bridging Orbit and Classroom:
SatNOGS and CubeSatSim Activities

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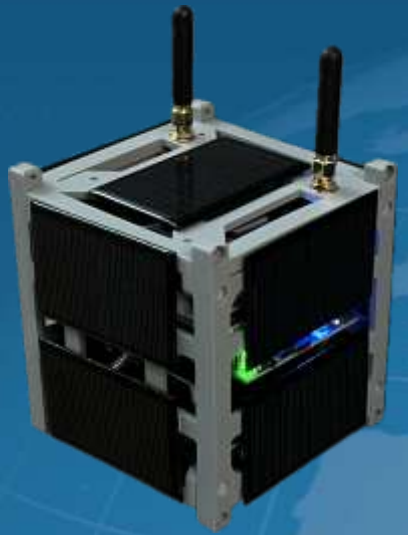
Topics

- What is the CubeSatSim
- What is SatNOGS
- How to adopt a satellite
- Using the CubeSatSim to interpret SatNOGS data
- SatNOGS operation
- Q & A

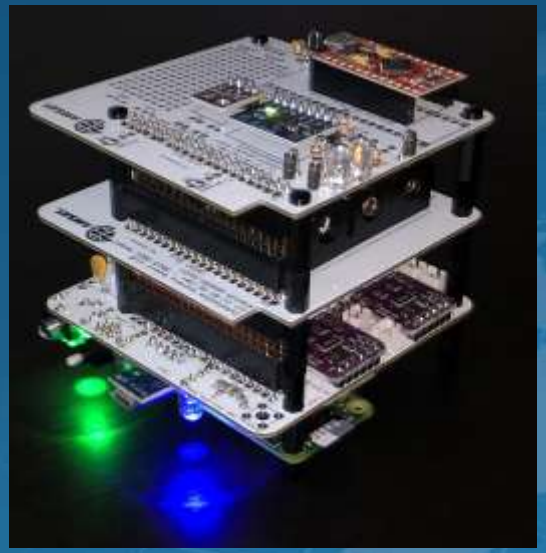
AMSAT CubeSatSim

- A low-cost ($350 - $500) satellite emulator that runs on solar panels in sunlight, batteries in eclipse, and transmits UHF radio telemetry using the most commonly used transmission modes and protocols.



AMSAT CubeSatSim

- Uses a 4-board stack that contains a Raspberry Pi single board computer, an Arduino compatible microcontroller, rechargeable batteries, voltage/current sensors, and environment sensors.

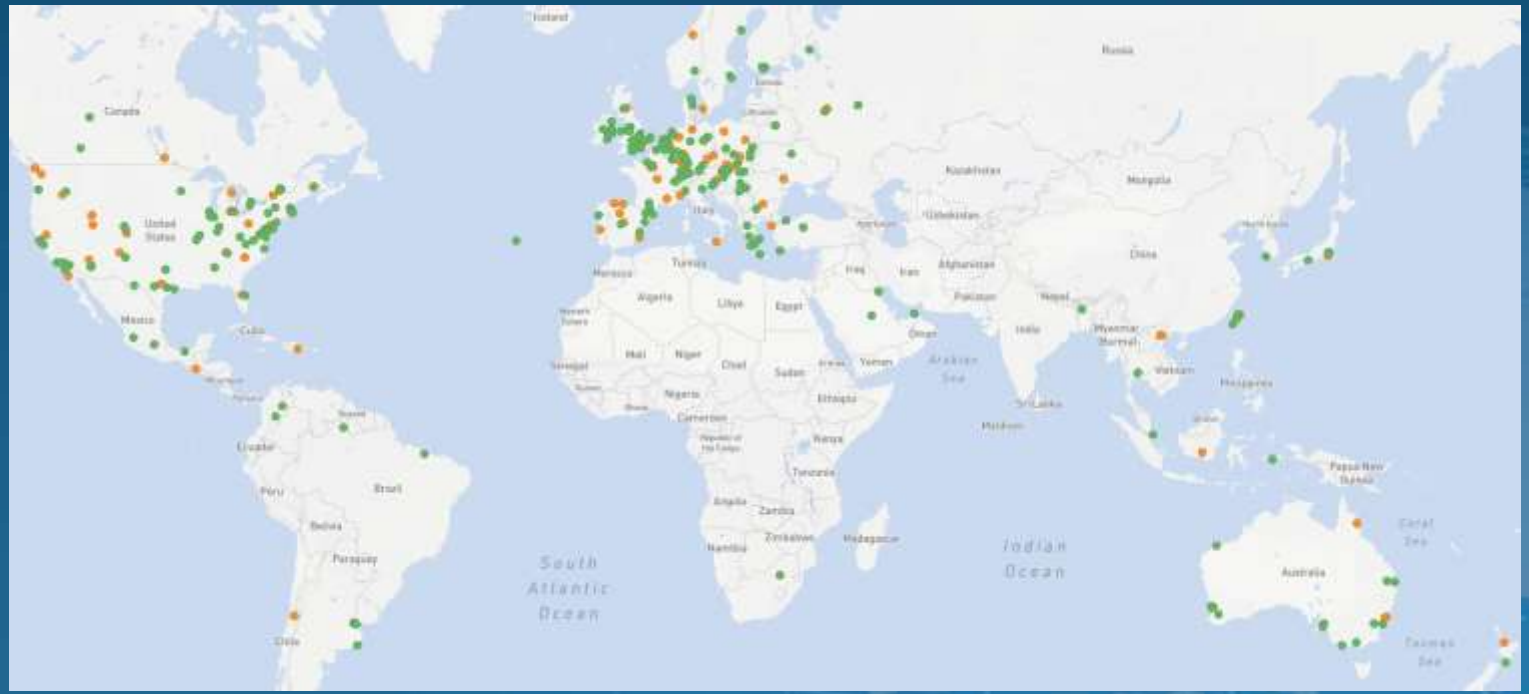


CubeSatSim Features

- Two processors: flight & payload
- Six solar panels, each with voltage & current monitoring
- Expandable payload via I2C sensors
- Raspberry Pi camera
- UHF radio using 5 telemetry modes
- Open Source hardware and software
- Open Source Raspberry Pi / RTL-SDR ground station
- **FREE loaners available for educators and demonstrators**

What is SatNOGS?

- Global network of open-source ground stations operated by educational institutions, hobbyists and space enthusiasts.



What is SatNOGS?

- It’s an Open Access database containing more than 12 million observations from 2300+ satellites.

What is SatNOGS?

- Dashboards provide visual access to operational data

What is SatNOGS?

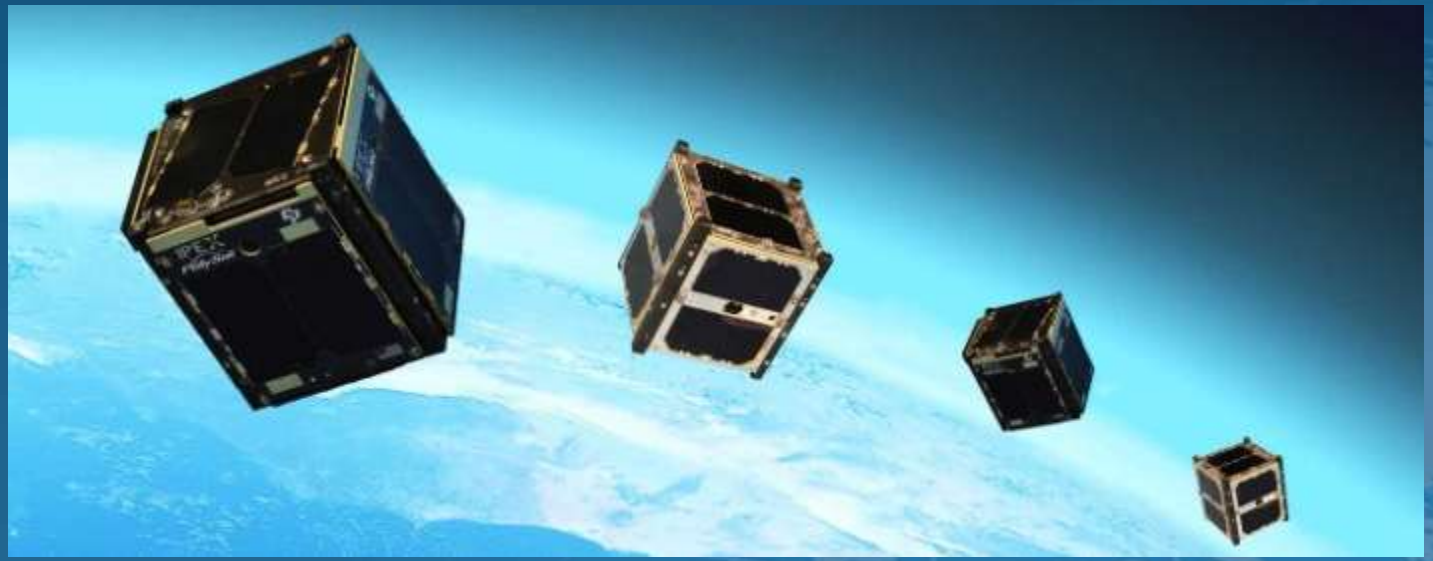
- Access to DB and dashboards is free to everyone
- You can build an operating SatNOGS station for $150 US
- As a station operator, you can schedule data downloads on other stations.

Why Adopt a Satellite?

- Once a CubeSat is on-orbit, its operators need to continuously monitor its health and collect scientific data.
- By “adopting” an existing, on-orbit satellite, students have the experience of being a satellite operator without the expense and risk of launching your own CubeSat.
- Using published information, students learn about their “adopted” CubeSat, its mission and orbital path, the communications protocols used and data returned, etc.
- By using SatNOGS to schedule data downlinks & monitor the CubeSat’s dashboard over a 1 - 4 week period, students learn about CubeSat communications, operations and performance.

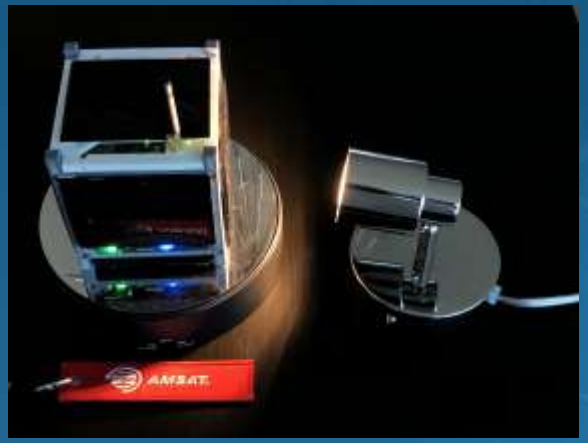
The Problem

- How to interpret SatNOGS telemetry and relate it to a satellite's orientation and behavior in space.

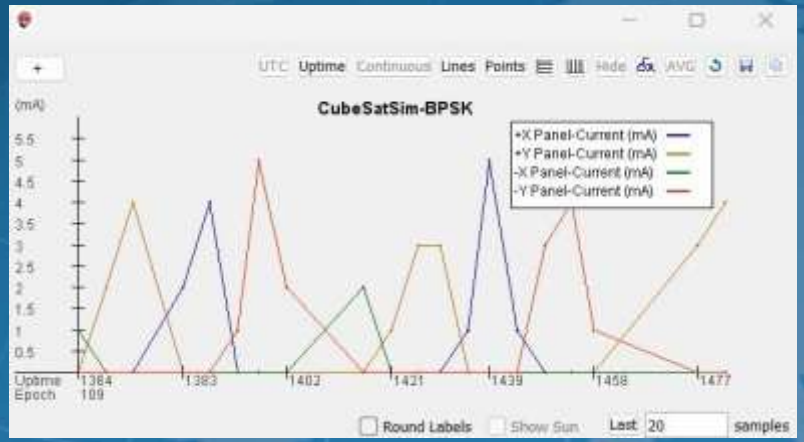


The Synergy: CubeSatSim to Interpret SatNOGS Data

- The CubeSatSim provides a controlled, hands-on environment to collect and interpret data. It can be held stationary and can be manipulated, enabling student to relate telemetry values to the CSS orientation and movement.
- This direct experience offers the practical context necessary to fully appreciate and analyze the real-world, dynamic data streams provided by the SatNOGS.



CSS spining on turntable



Resulting FoxTelem plot

Solar Cells & Power Management

- CubeSatSim Activity:
  - Measure and record differences in solar panel output, battery voltages and currents, and power consumption and generation under varying light conditions.
  - Observe voltage and current changes as the CubeSat enters and leaves simulated eclipse conditions.
  - Determine solar panel failures or performance issues.
- Connecting to SatNOGS Housekeeping Data Interpretation:
  - This direct, hands-on experience allows students to interpret the solar cell performance (voltage & current) and power management data they see on SatNOGS dashboards from real satellites.
  - They gain insight into the fluctuations in power generation and consumption as a real satellite moves between sunlight and eclipse

CubeSat Orientation and Spin Rates

- CubeSatSim Activity:
  - Students determine the CubeSatSim’s orientation using accelerometers and solar cells.
  - They learn to determine its spin rate using gyroscopes and solar cells.
  - Students can directly manipulate the CubeSatSim to understand the relationship between the telemetry data and a satellite’s orientation in space.
- Connecting to SatNOGS Housekeeping Data Interpretation:
  - This hands-on understanding of how sensor data reflects a satellite's physical state helps students infer a real satellite's orientation and spin rate from SatNOGS data.
  - This is particularly useful when observing patterns in solar panel outputs and other sensor readings over time on SatNOGS dashboards, which can indicate changes in orientation.

Radio Communications & Decoding Protocols

- CubeSatSim Activity:
  - The CubeSatSim transmits UHF radio telemetry using five commonly used modes.
  - Students utilize ground station software to receive, decode, visualize, and record this telemetry, providing direct exposure to the conversion of radio signals into interpretable data.
  - They learn firsthand about different communication (RF) modes by experimenting with the CubeSatSim's multiple telemetry modes.
- Connecting to SatNOGS Displays and Dashboards:
  - This activity directly informs students' understanding when using SatNOGS displays to interpret "waterfall signals turned into bits," "bits turned into data," and "data turned into information" on dashboards.
  - The practical experience with the CubeSatSim's communication features helps demystify the complex communication principles observed in SatNOGS.

Satellite Communications

- Why do SatNOGS waterfalls look different?
- Answer: each is a different communications (RF) mode
- CSS with Fox-in-a-Box SDR software reproduces many of these modes.

GFS 9K6

APRS

APT – Weather Satellite

Morse Code w Other Sats

Local Interference w Doppler Shift

How to Adopt-A-Satellite

- Explore SatNOGS.org
- Assemble a minimal station and start scheduling observations
- Assemble students into teams of 3 - 5
  - Each team picks a satellite for adoption
  - They learn everything they can about their satellite
  - They schedules downlinks across the global network, monitor received data and compare data to historical data for the specified time period
  - They present their findings to the class.
  - Optionally, they track newly launched satellites (more to come...)

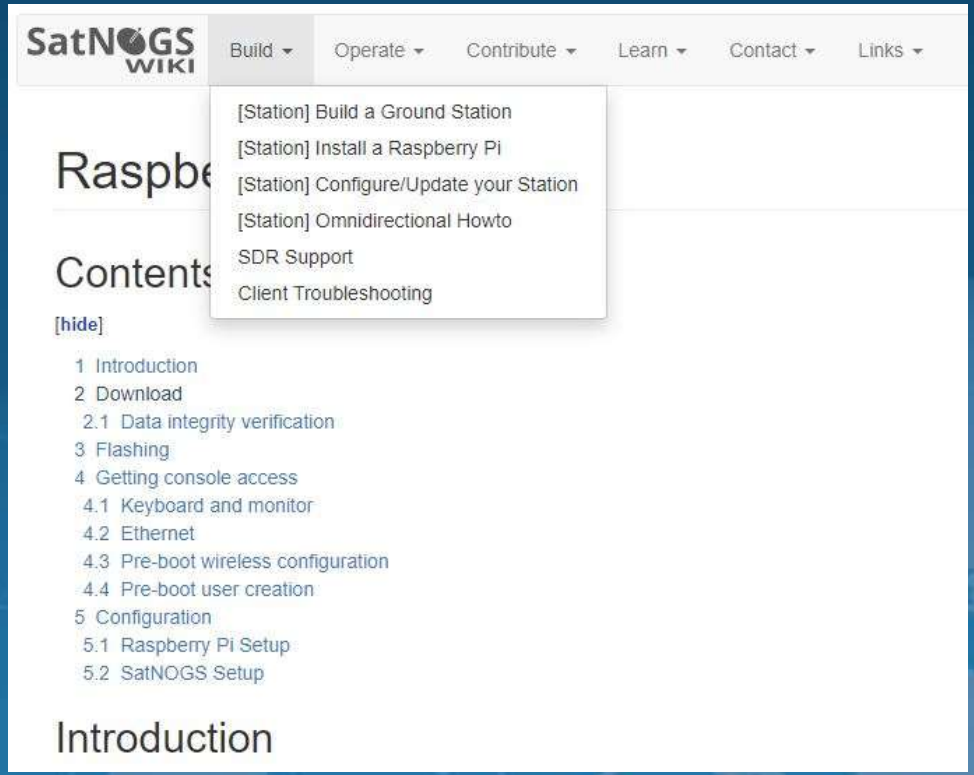
Assemble a Minimal Station

- Raspberry Pi 3B+ (or better) kit with micro-SD card

RTL-SRD.COM SDR stick with antenna kit

Assemble a Minimal Station

- Follow the step-by-step instructions on the SatNOGS wiki
- Download and flash the SD card image
- Boot and configure
- Once configured, use SSH to remotely access the RPi (if necessary)



Picking a Satellite to Adopt

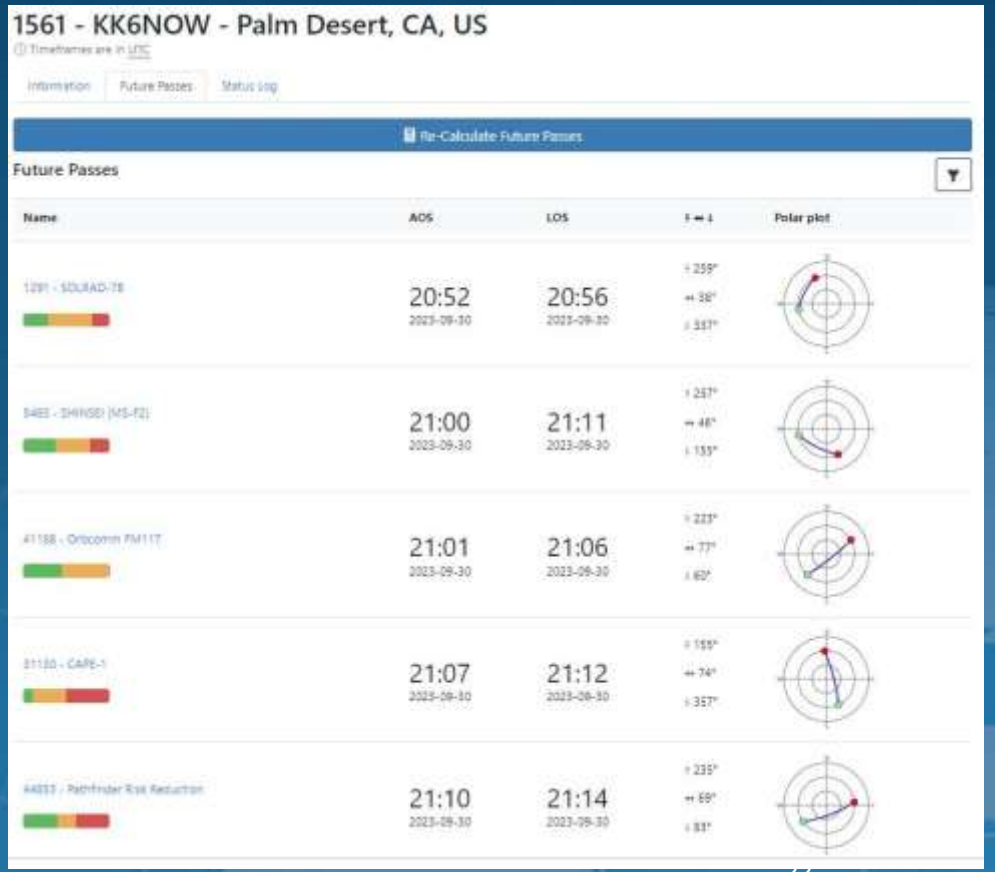
- Has a SatNOGS dashboard
- Is currently active
- Is successfully received by numerous stations
- You can easily find data about the satellite on the Internet
- Has more than 6 months of on-orbit data available
- Examples:
  - ISS (International Space Station)
  - CIRBE – lasp.colorado.edu/cirbe
  - GRIFEX – jpl.nasa.gov
  - CubeBel-1 & 2 – bsusat.com
  - UVSQSat – latmos.ipsl.fr

Satellite Operations

- Schedule global observations for coverage of at least 2 weeks
- Solar cell performance: voltage & current on each panel
- Power management and battery performance
- Thermal management: multiple sensors within the satellite
- Observe voltage, current and temperature changes over time
- Attempt to determine orientation and spin rate
- Optionally use orbit predicative software to plot altitude
- These are some of the parameters you would monitor if this was your CubeSat.

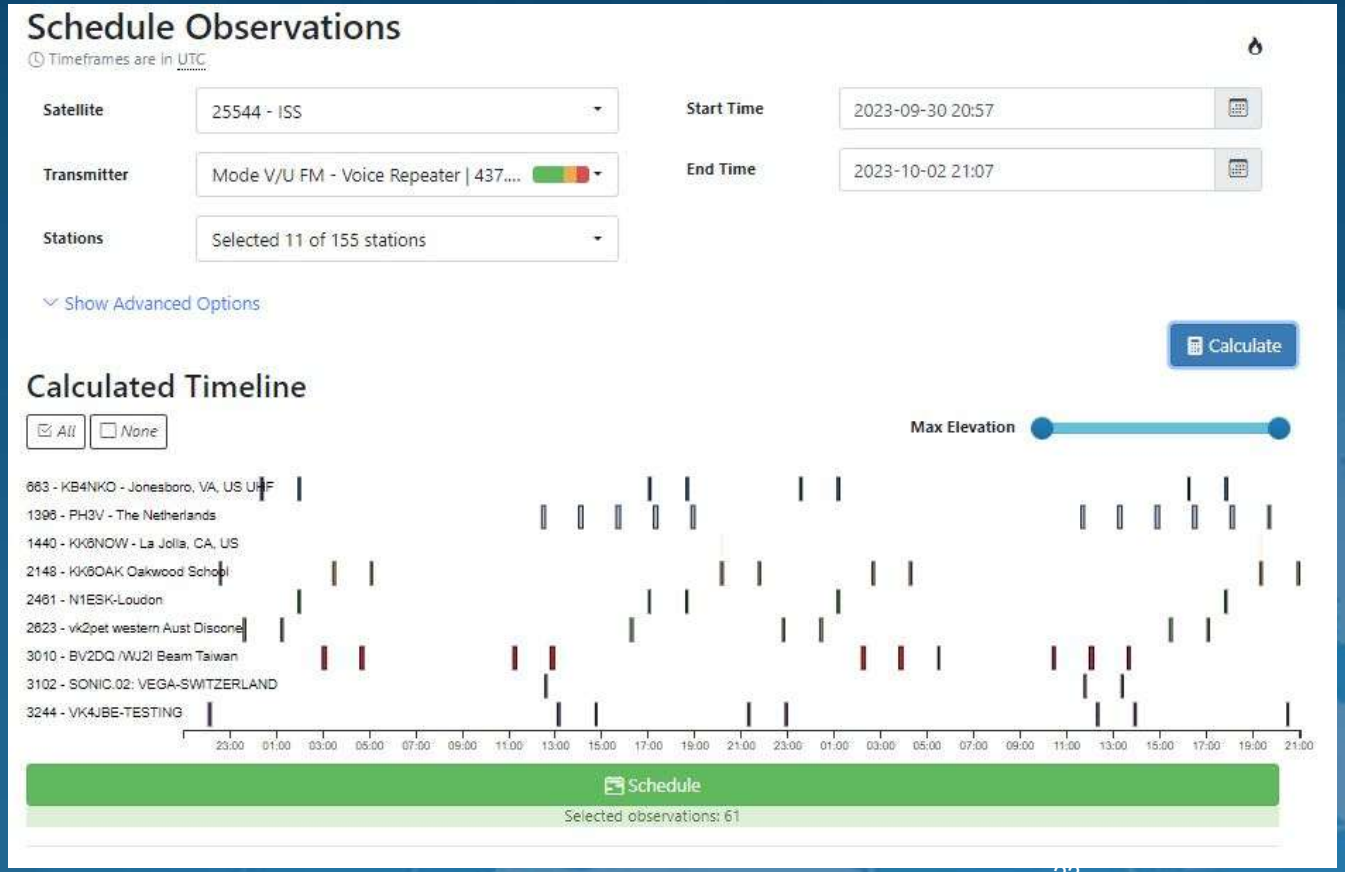
Observation Scheduling

- Schedule by station



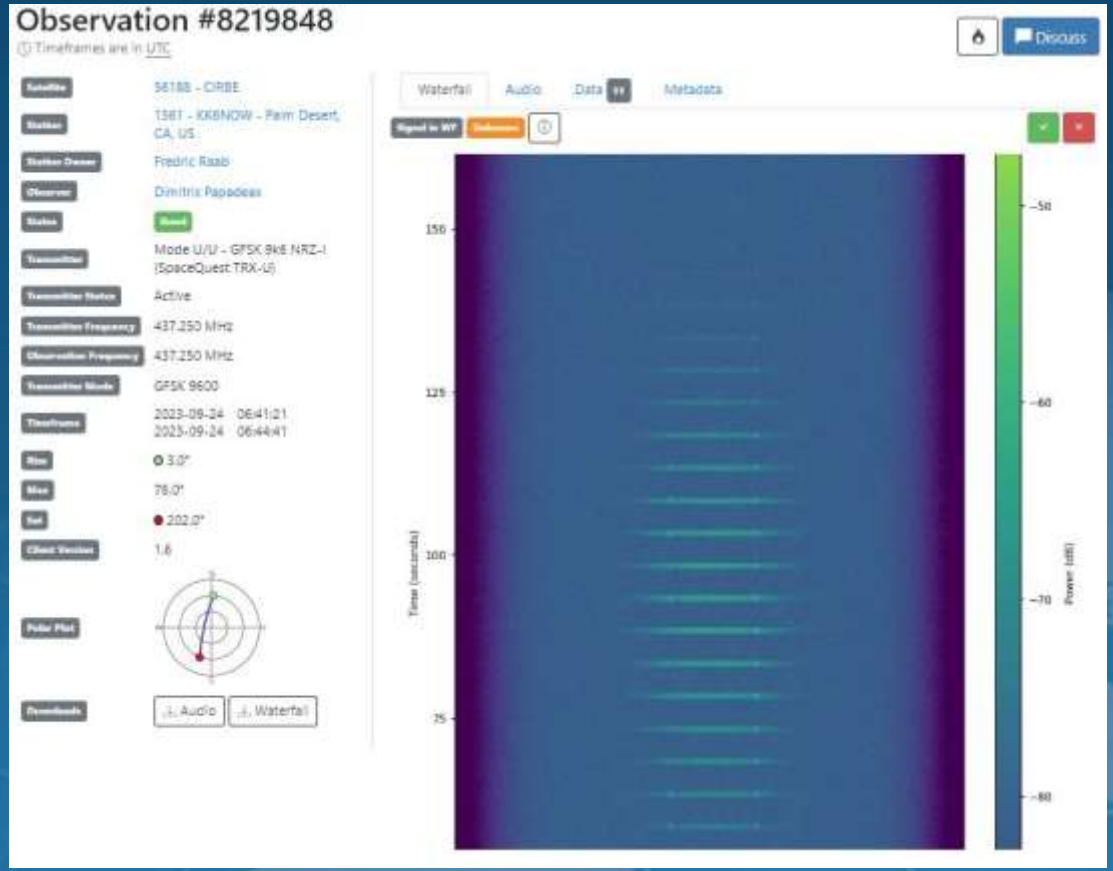
Observation Scheduling

- Schedule by satellite
- Up to 2 days in advance
- Across multiple stations
- Across multiple timezones


Schedule Observations
Timeframes are in UTC
Satellite
25544 - ISS
Start Time
2023-09-30 20:57
Transmitter
Mode V/U FM - Voice Repeater | 437....
End Time
2023-10-02 21:07
Stations
Selected 11 of 155 stations
Show Advanced Options
Calculate
Calculated Timeline
All
None
Max Elevation
663 - KB4NKO - Jonesboro, VA, US UHF
1396 - PH3V - The Netherlands
1440 - KK6NOW - La Jolla, CA, US
2148 - KK6OAK Oakwood School
2461 - N1ESK-Loudon
2623 - vk2pet western Aust Discone
3010 - BV2DQ /WJ2I Beam Taiwan
3102 - SONIC.02: VEGA-SWITZERLAND
3244 - VK4JBE-TESTING
23:00 01:00 03:00 05:00 07:00 09:00 11:00 13:00 15:00 17:00 19:00 21:00 23:00 01:00 03:00 05:00 07:00 09:00 11:00 13:00 15:00 17:00 19:00 21:00
Schedule
Selected observations: 61

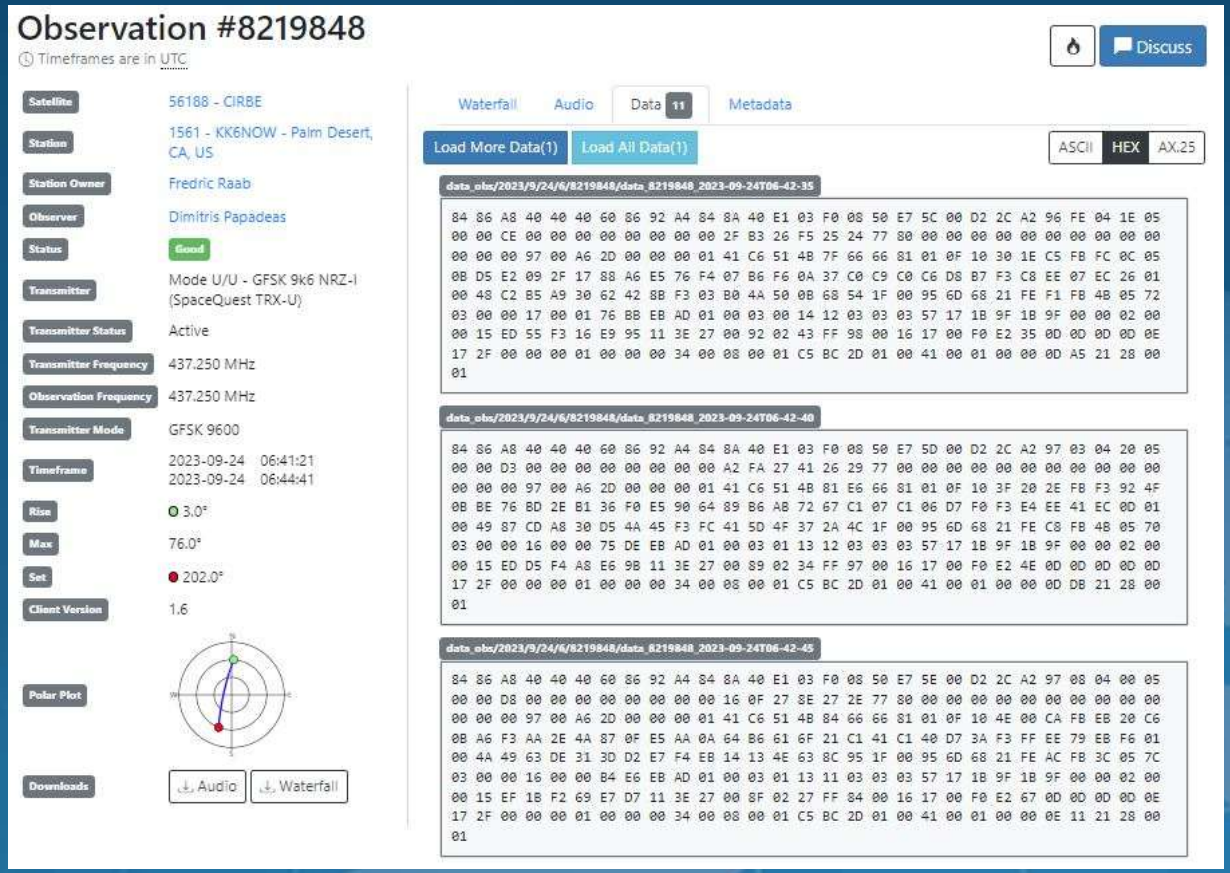
Observation interpretation

- Waterfall provides a visual representation of the signal and strength over time
- Click green & red buttons (far right) to indicate good signals
- Use tabs to listen to signal, view data packet
- Left column provides metadata about the observation



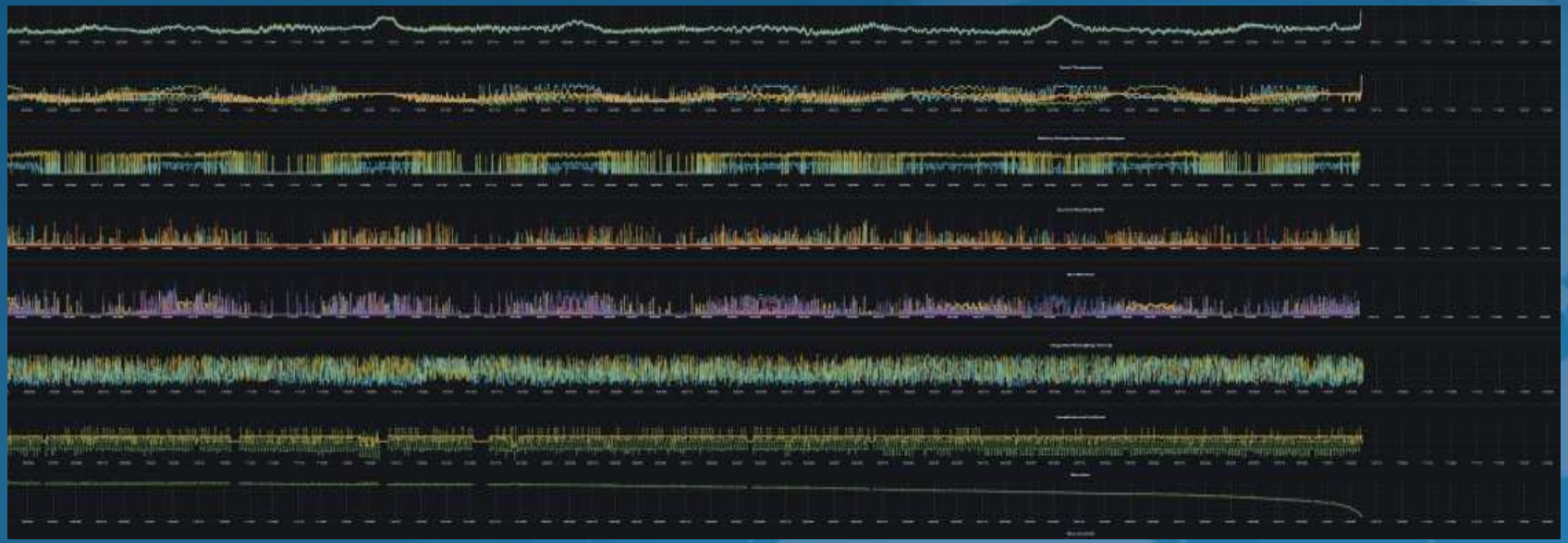
Decoding Communications Protocols

- Questions to explore:
  - How are waterfall signals turned into bits?
  - How are bits turned into data?
  - How is data turned into information that can be displayed on a dashboard?



Dashboards and Housekeeping Data

- Dashboards provide time-series data at a glance
- Shows patterns over time making it easier to detect anomalies
- What happened here? *Hint: bottom graph is altitude.*



Tracking Newly Launched CubeSats

- Deployments are announced on discussion boards
- Bragging rights to the first station or user to receive a signal
- Providing a valuable service to the CubeSat's owner
- Provides a level of anticipation and involvement for your students
- Fun but frustrating: expect many observations with no signals.

SpaceX F9 Transporter-8 - 2023-06-12 21:35 UTC

Satellites & Observations ■ Launches

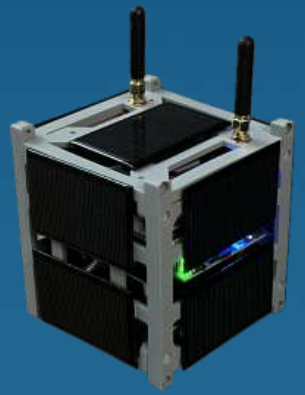
Temporary NORAD ID	Satellite	Frequency	Notes	Deployed
COMMERCIAL UHF				
99258 11	GHOST-3	400.5 MHz		Directly
99098 12	Otter Pup	400.5 MHz		Orbiter SN3
99081	Tomorrow R2	400.5 MHz	Former unknown satellite with the name "Transporter 8 Satellite B"	Directly
99082	Transporter 8 Satellite C	400.503 MHz	Merged with GHOST-3	Directly
99079	AII-DELTA	401.05 MHz	Former unknown satellite with the name "Transporter 8 Satellite E"	Unknown
99078 2	Transporter 8 Satellite F	401.05 MHz	Unknown Satellite, possible match is AYRIS-2 according to the pre-launch TLE from Celestrak	Unknown
99192 1	Istanbul	401.075 MHz		ION SCV-011 - Alba Orbital Cluster 7

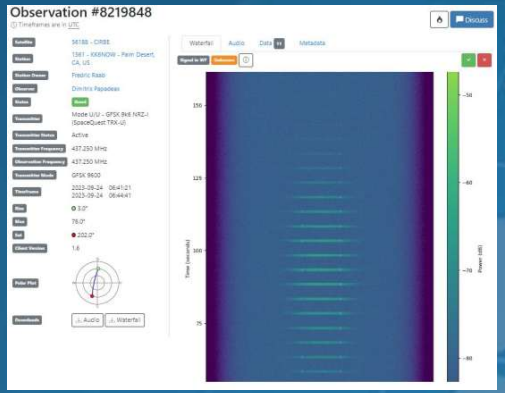
Summary of Learning Objectives

- Telemetry interpretation
- Satellite communications
- Decoding communications protocols – bits to data
- Interpreting dashboards and housekeeping data
- Satellite components
- Satellite operations
- Scientific missions
- Tracking newly launched CubeSats

In Conclusion:
From Classroom to Orbit

- CubeSatSim provides the hands-on experience of building a CubeSat and the means to understand how telemetry data relates to a satellites performance in space.
- SatNOGS provides access to telemetry data from orbiting satellites and the experience of being a satellite operator.
- Without the expense and risks of a launch.





Q & A

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www.FredricRaab.com

SatNOGS.org

CubeSatSim.org

www.amsat.org